New Tools for Ocean Exploration, Equipping the NOAA Ship *Okeanos Explorer*

Justin E. Manley

Battelle[1], Duxbury, MA
http://www.battelle.org, manleyj@battelle.org

NOAA Office of Ocean Exploration[1], Silver Spring, MD
http://oceanexplorer.noaa.gov, justin.manley@noaa.gov

***Abstract* - In 2004 the US Navy transferred the USNS Capable (T-AGOS 16) to the National Oceanic and Atmospheric Administration (NOAA). The vessel has recently completed an extensive conversion effort to become the NOAA Ship *Okeanos Explorer.* NOAA's Office of Ocean Exploration and Research (OER) will use the vessel to conduct multi-disciplinary ocean exploration and research projects. OER's goal is to increase America's knowledge of the U.S. Exclusive Economic Zone and other areas of the roughly 95 percent of the underwater world not previously explored and largely unknown.**

As a new vessel dedicated to ocean exploration the *Okeanos Explorer* received significant upgrades and new equipment. This paper describes the major facets of the conversion. The *Okeanos Explorer* will be the first NOAA vessel to carry a dedicated remotely operated vehicle (ROV) and systems designed to connect the ship and ROV activities to shore via "telepresence." The development and integration of these new technologies on the vessel is also described. The paper concludes with a discussion of how OER envisions these tools being employed in ocean exploration.

I. Introduction

A. NOAA Ocean Exploration Background and Scope

The oceans and great inland seas are widely recognized as among the few remaining frontiers of human discovery on our planet. History demonstrates that exploration results in discoveries of great value. Every ocean expedition has the potential to discover important information about the origins of life on earth, or new living or non-living resources that may have potential to benefit humanity. Recent progress in technology is enabling new initiatives. Ocean exploration assets and capabilities may one day rival those of space exploration, with potential for enormous economic, archeological, health, and quality of life benefits.

The national need to explore the ocean and large inland lakes was an important rationale stated by the Stratton Commission in 1969 for establishing the National Oceanic and Atmospheric Administration (NOAA) as an organization [1]. The importance of this mission was reinforced in October 2000 by a national panel of ocean experts appointed by the President of the United States in its report: *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration* (hereafter referred to as the *Frontier Report)* [2]. The panel noted that the same reasons that motivated early explorers to accept great risks in their search for new discoveries—survival, inspiration, wealth, and national pride—provide fundamental justification for embarking on a new era of ocean exploration:

"Exploration is fundamental to the human spirit. Since the dawn of our species we have been explorers, with the motivation for these journeys ranging from survival to spiritual inspiration."

The *Frontier Report* provides a comprehensive vision for exploring the oceans that continues our national legacy of seeking new knowledge at the great frontiers of human discovery. Subsequently the U.S Commission on Ocean Policy has reinforced this imperative toward exploring our ocean planet [3]. NOAA has recognized the important role of the Federal government in achieving this vision throughout the history of our Nation and has assumed a leadership role in implementing a program for systematically exploring the ocean through its Office of Ocean Exploration and Research (OER).

As a principal component of the national strategy for exploration, OER seeks to bring the best of the nation's scientists to the leading edges of ocean science and technology to (1) discover more about life and processes within the oceans, (2) learn more about maritime cultural resources and heritage, (3) reap the benefits of the ocean's biological and mineral resources and (4) share new knowledge across a broad, multi-disciplinary user community. In the ongoing efforts to meet these goals OER is working across NOAA, other federal agencies, academia and the private sector to foster the development and deployment of state-of-the-art ocean technologies.

B. A Dedicated vessel

The *Frontier Report* envisioned ocean exploration supported by dedicated vessels free from rigid schedules and equipped with tools to identify and explore targets of

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interest. The first step in this vision was enabled in 2004 when the US Navy transferred the USNS Capable (T-AGOS 16), Fig 1, to the National Oceanic and Atmospheric Administration (NOAA). It has a length of 224 feet (68 meters), a beam of 43 feet (13 meters) and displaces 2,262 tons (2,298.3 metric tons). The vessel was originally configured for surveillance activities in the Pacific Ocean. NOAA had previously accepted other T-AGOS class vessels and thus was able to begin a program of conversion to meet the new requirements.

Fig 1. The USNS *Capable* prior to conversion (courtesy NOAA)

II. Conversion of the *Okeanos Explorer*

The conversion of the USNS *Capable* to the NOAA Ship *Okeanos Explorer*, Fig 2, required significant modifications. The transition from a slow cruising vessel for towing acoustic arrays into a dedicated platform for deep ocean exploration required significant new infrastructure across the vessel. Basic maintenance and repairs were conducted and all work was certified to American Bureau of Shipping (ABS) standards. Habitability improvements were also made. While important these efforts are not the focus of this paper, changes specific to the exploration mission are described here.

Fig 2. The *Okeanos Explorer* (courtesy NOAA)

A. Dynamic Positioning

A key capability for operating deep ocean remotely operated vehicles (ROVs) is dynamic positioning (DP). To add DP to the vessel required the installation of new thrusters. Two fixed thrusters were added in the stern skeg, forward of the main propellers. These tunnel thrusters are complemented by a fully azimuthing bow thruster. This unit can operate as a fixed tunnel thruster in its retracted configuration. It can also be lowered below the keel-line in which position it becomes directional allowing for greater control. Associated electronic control and positioning systems were added to provide the closed-loop control using these new thrusters and the twin propellers aft. This element of the conversion is new to NOAA and specific performance expectations for the DP system are uncertain. As of the time of writing the system had not yet undergone significant sea trials. Nonetheless it is expected that heavier wind and sea conditions will require the ship to "weathervane" so that the main propellers can be used against the largest displacement forces.

B. ROV Infrastructure

In addition to the DP system the vessel was also optimized for ROV operations. Significant changes were made to interior spaces and the aft deck. Lifting gear including a dedicated crane and a custom A-frame were installed. A traction winch and approximately 8,000 meters of 0.68" umbilical cable were installed below decks in a converted tank space. A hangar large enough to accommodate the expected ROV was added on the port side of the vessel opening on to the fantail. A track system and hydraulically actuated cart were installed to move the ROV in and out of the hangar. Two interior spaces were custom configured for ROV needs. Once space is a "rack room" where electronics, servers and similar gear are installed for ease of access and maintenance, Fig 3.

Fig 3: The Rack Room (courtesy Phoenix International)

Adjacent to this compartment is a dedicated control room, Fig 4. Whereas traditional ROVs make use of "vans" to house the controls, screens and operator stations for an ROV these items are all permanently installed in a compartment of the vessel. This provides for a more comfortable and functional space accessible without exposure to weather decks. A final addition to the ROV infrastructure was the installation of an ultra-short baseline (USBL) acoustic tracking system hydrophone in the new transducer fairing on the keel. This same fairing houses the transducers for the

multibeam sonar that will support baseline mapping prior to ROV exploration.

Fig 4: The ROV Control Room (courtesy Phoenix International)

C. Telepresence Infrastructure

In addition to ROV operations a key requirement for the *Okeanos Explorer* is the ability to support high bandwidth satellite telemetry to shore. This will enable "telepresence" in which audio and video feeds (including high definition video) will be returned to shore via satellite. Infrastructure for this capability includes a 3.7 m dish antenna mounted atop the mast. The antenna is actively motion compensated but as of the time of writing there is still some uncertainty as to the maximum sea state it can endure safely. The rack room adjacent to the ROV control room is also a key component in supporting the telepresence equipment.

III. The Remotely Operated Vehicle

To provide an ocean exploration ROV NOAA chose to compete the acquisition program. Phoenix International of Largo, MD won the contract. The development and design philosophy of this vehicle have previously been presented [4,5] and novel, but not unique, features of the ROV include high definition cameras and closed loop position control. Other more distinctive features merit some further discussion.

The most obvious feature of the ROV design is its two-body layout. This provides for a "smart" depressor sled equipped with cameras and lights of its own, Fig 5. This unit is mated to the vessel by a standard armored umbilical. The sled is then connected to the ROV, Fig 6, via a flexible, neutrally buoyant tether. The primary functionality of this design is to provide an independent light source, separated by some distance, from the ROV. This reduces optical backscatter and improves the quality of the video data provided to the science users. This also allows the sled to provide an "overhead" view of the ROV at work. This perspective has proven to be of great value to scientists who can see the ROV in the context of the site being explored.

Fig 5: The Camera "Sled" (courtesy D. Lovalvo, Eastern Oceanics)

Fig 6: The ROV (courtesy D. Lovalvo, Eastern Oceanics)

A significant innovation on this vehicle is the development of a new electro-optical (EO) termination that allows for quick connection and disconnection of the tether between the vehicles. This connector allows for quick replacement of failed tethers or to switch to a camera platform only mode for operations when launch and recovery of the full two-body system is prohibited by weather or other operational conditions. This is believed to be the first quick mate EO connector designed to both mechanically carry the full load of the ROV, plus a significant safety factor, and function at depths to 6,000 meters. As of time of writing the tether and connector had not been field-tested. As a new technology it is possible that the expected performance will not be observed in practice. Conventional termination approaches are in readiness if required.

A final distinctive feature of the ROV embarked upon the Okeanos Explorer is the inclusion of a small battery powered ROV called an x-Bot. This vehicle uses a thin fiber-optic tether for control allowing it to penetrate confined spaces. While NOAA does not practice shipwreck penetration, exploration missions may benefit from such capabilities in exploring submerged caves or complex hydrothermal vent sites.

The ROV system, as of time of writing, has been delivered to and integrated upon the *Okeanos Explorer*. Sea acceptance trials have not yet been completed. NOAA anticipates completion of these trials by the end of 2008.

IV. Telepresence

The “telepresence” equipment on the Okeanos Explorer included both the high bandwidth satellite communications system and additional equipment required to share the shipboard experience with other participants onshore.

The satellite telemetry consists of a very small aperture terminal (VSAT) system that should provide data at rates up to 21Mb/s from the ship to the shore and up to 4 Mb/s from shore back to the ship. Operating at these high speeds requires advance planning and non-trivial budget resources. This capability is required to support full transmission of the high definition video from both the ROV and auxiliary cameras about the ship.

In addition to conventional Internet access and other common computing resources the satellite network will also be interfaced to equipment required for remote science. This consists of the following subsystems: (1) a 1080i HD/SD/analog video routing subsystem; (2) an analog/digital audio routing subsystem; (3) an HD/SD video collection and storage subsystem; (4) a HD video encoding and IP encapsulation subsystem; (5) a HD/SD video frame capture subsystem; (6) an intercom with VoIP capability; (7) a multi-display subsystem; (8) remotely controlled HD PTZ cameras; (9) a video editing station; (10) and KVM and VGA distribution for a limited number of computers.

This system is connected through a hub onshore to Exploration Command Centers (ECCs), which allow operators at those stations to participate in the activities onboard ship. ECC watch standers use the intercom and computer/video distribution capabilities to interact with their colleagues at sea. The technical and operational details of these operations could fill several papers. Much like the other new tools on the *Okeanos Explorer* significant testing and use of these systems will await upcoming sea trials. Thereafter it is expected that the telepresence will bring new discoveries to scientists and the public onshore in real-time.

Over standard Internet connections, telepresence brings the excitement of ocean exploration from the seafloor live into class rooms, newsrooms, and living rooms, helping to raise ocean literacy among stakeholders who will then be better able to make important decisions about ocean issues. This technology serves constituents across the ocean community while also opening a new era of ocean exploration for NOAA.

V. Looking Forward

A. Three modes of exploration

Through the NOAA Science Advisory Board’s Ocean Exploration Advisory Working Group (OEAWG), the OER received input on different modes of operation that could be implemented during the course of a field season. OER staff and partners have worked to define these models with the objective of testing and evaluating them during “Field Trials” of the *Okeanos Explorer*. These modes are described below.

Site Characterization. Site Characterization is defined as working at a specific target location where there is some background information to work from and the discovery potential is high. A site characterization field trial cruise will use most of the ship and ROV capabilities, and dedicated broad-band satellite time for telepresence operations will be scheduled. The objective will be to map and explore the seafloor and bottom features, as well as to characterize the water column above the target location. The objectives include developing standard products to ensure a consistent portfolio of data and information, enabling OER and other programs and institutions to make decisions concerning follow-up exploration, research, and even management activities for the target location.

Water Column Exploration. The science community has expressed interest in testing the ability of the ship and its systems to explore and investigate the water column. Although it is not envisioned that the ship would ever execute an expedition focused solely on the water column, there is value in scheduling such dedicated field trial cruises during the first year of operations in order to: (1) improve the ability to characterize the water column during site characterization; (2) improve the ability to search for anomalies during reconnaissance expeditions; and (3) determine how to maximize the use of the ship and systems during transits through poorly known areas where the water depth exceeds the limits of the multibeam and ROV. Ewing stations – defined as stopping once each 24-hour day to collect water column data (numeric data, visual data, and limited samples) – would be a key component of such a cruise. Dedicated broad-band satellite time for telepresence operations would not be required for this field trial cruise. Objectives include developing standard products that complement information collected through other manned and unmanned assets such as the Argo profiling CTD floats.

“Sticks-and-Boxes” Reconnaissance. Reconnaissance is defined as transiting through unknown and poorly known waters (sticks) within the depth range of the multibeam and ROV with the express purpose of making a discovery and initiating Site Characterization operations (boxes) as described above. It is envisioned that this will

ultimately be the primary operating mode for the ship. Ewing stations as described above would be part of this operating mode. Such a field trial cruise will test all of the capabilities of the ship, and will require dedicated broad-band satellite time for telepresence operations. Standard products would include elements of both Site Characterization and Water Column Exploration. The length of time spent on a "discovered" target would be based both on an initial assessment of the detailed data collected, as well as the preplanned time-frame for the cruise.

B. Next Steps

As of the deadline for this paper submission, the *Okeanos Explorer* has completed conversion. Telepresence and ROV equipment has been installed and integrated. Some aspects of sea acceptance trials have been completed but others, notably open water ROV test dives to significant depth, have not yet been conducted. The vessel will be formally commissioned in August 2008 and sea acceptance trials of the ROV are expected after that. Until this phase is competed it is premature to predict when the vessel will begin its exploration mission in earnest. However, NOAA is looking forward to new discoveries made by the *Okeanos Explorer* and its new tools sometime in 2009.

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